

Filling up the Two-Body Partial Decay Width of P-Wave Charmonia with the Color Octet Contribution

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Quarkonia are special hadronic systems in which the constituent quarks because of their large mass move very slowly therefore they are open to non-relativistic treatment. So quarkonium production or decay, once supplemented with non-perturbative wavefunctions or matrix elements can be calculated using the small velocity as an expansion parameter [1]. Recently some exclusive χ_J decay channels have been re-measured at the Beijing Spectrometer by the BES collaboration [2]. An attempt to compare with existing calculations of the channels $\chi \rightarrow \pi\pi$ and $\chi \rightarrow p\bar{p}$ revealed that these were out-of-date. Various parameters have changed since the last serious attempts at calculating the partial widths and the understanding on some of the hadronic wavefunctions has also improved. It is therefore necessary to re-examine the decay calculations.

The decay processes of interest are best calculated using the perturbative QCD based scheme of Brodsky and Lepage (BL) [3]. In this scheme, decay amplitudes are given by a convolution of non-perturbative hadronic distribution amplitudes and the associated perturbative hard part through which the hard momentum flows. Using this scheme with the latest parameters such as Λ_{QCD} , decay constants and distribution amplitudes of pion and nucleon, it was found that in both channels the theoretical width of the $c\bar{c}$ system fell far short of the experimental results. The widths for the decay into $\pi\pi$ are at most 23% for χ_0 and 28% for χ_2 of the experimental data. Those for the decay into $p\bar{p}$ are even worse at only 8.3% for χ_1 and 10.4% for χ_2 . The next logical step to find out why there are such large discrepancies is to try the calculations again using the improved BL scheme of Sterman et al [4] hoping that the advantages in the improved scheme could compensate for whatever in the original scheme that might have caused the deficiencies [5]. Unfortunately this is not to be. The new scheme actually yielded widths of the same magnitude as obtained from the old. Varying all parameters within their uncertainties to enlarge the widths did not help either. The results were still at least a factor of two or more below. The widths at the size of the experimental data remained unattainable. So the small theoretical results did not arise because of some artifact in the scheme or the poor choice of parameters used.

While searching for an explanation, it became obvious that color octet might be the answer as this was shown to be a necessary component in inclusive P-wave charmonium decay to ensure infrared finite answers [1, 6]. Strangely color octet has never been considered within the context of exclusive reactions. At first sight it cannot be the answer because higher Fock state contributions are suppressed by large momentum flow within the BL scheme. On the other

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hand, a contradiction would arise if none of the exclusive χ_J decay channels, many-body decays included, requires the octet contribution. This is because the octet state must be there to ensure infrared finite inclusive width, which is just the sum of partial widths of all exclusive channels.

An examination of the charmonium wavefunctions show that in momentum space the P-wave wavefunction is down by k/M in comparison to the S-wave due to angular momentum, where k is the internal momentum of the heavy quarks within the charmonium and M is the mass of the latter. Extending this consideration to the decay amplitude of the $\pi\pi$ and $p\bar{p}$ channels, it can be shown that by examining the large mass M dependence within the BL scheme that the singlet and octet amplitudes for the decay into $\pi\pi$ go like $1/M^3$ and those for $p\bar{p}$ channel both also have the same dependency of $1/M^5$ [7]. So despite the fact that the octet is a higher state, it is not suppressed relative to the valence state. The suppression of the higher state in this case can no longer be thought of as one when the P-wave valence state is brought down to the same level by the orbital angular momentum. Once this theoretical hurdle has been overcome, it remains to work out new ingredients to be used in the calculations. One is the yet unknown wavefunction of the color octet state and the other is more about the practicality of what to do with the constituent gluon. Neither of these was ever needed or encountered in the calculations of exclusive processes. Nevertheless the former can be modeled and fit to data, and the latter argued to yield a dominant contribution if the constituent gluon line ends on the hard part in the Feynman graphs [8]. With these details sorted out, it was found that indeed the color octet contributions were capable of bringing the theoretical widths up to the size of experimental data [7, 8]. Thus confirming the theoretical expectations and resolving the problem of too small theoretical widths.

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